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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3041

SUMMARY OF REVISED GUST-VELOCITY DATA OBTAINED FROM V-G RECORDS TAKEN ON CIVIL TRANSPORT AIRPLANES FROM 1933 TO 1950

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SUMMARY

This paper summarizes gust-velocity data obtained by reevaluating the normal accelerations and airspeeds from V-G records taken on civil transport airplanes from 1933 to 1950. The reevaluation was made on the basis of a "derived" gust velocity U_{de}, which is related to the "effective" gust velocity U_e by a conversion factor that is a function of the type of airplane and operating altitude. Although the value of the conversion factor varies from about 1.6 to 2.0 for the data presented, the conclusions drawn from the previously presented data based on U_e (in particular, the relative levels of turbulence indicated between different routes) remain essentially unchanged.

INTRODUCTION

The National Advisory Committee for Aeronautics has for a number of years made use of normal-acceleration and airspeed data from V-G records taken during routine airline operations for determining the intensity and frequency of occurrence of atmospheric gusts. Gust velocities have been evaluated from these records by use of the gust-velocity formula given in the list of symbols of reference 1. The values obtained were expressed in terms of the "effective" gust velocity U_e. Recently, a revised gust formula was presented in reference 2 together with a discussion and comparison of the salient features of the old and the revised formula. One of the primary features of the revised formula is a new gust factor based on airplane mass ratio instead of wing loading. The gust velocities obtained by this formula are given in terms of a "derived" gust velocity U_{de} which for the same turbulence yields numerically higher values of gust velocity. Since the revised formula replaces the old gust formula in gust-load studies

and will be used in presenting future NACA gust research results, it appeared desirable to convert the available statistical data from terms of U_e to terms of the new gust velocity U_{de}.

This report summarizes in terms of the derived gust velocity U_{de} the reevaluated data obtained from V-G records of civil transport airplanes collected during the period from 1933 to 1950. Most of these data were presented in terms of the effective gust velocity U_e in references 3 to 7.

SYMBOLS

A	aspect ratio, b^2/S
b	wing span, ft
$\bar{c}$	mean geometric chord, ft
W	airplane weight, lb
S	wing area, sq ft
m	slope of wing lift curve per radian
g	acceleration due to gravity, ft/sec^2
ρ	mass density of air, slugs/cu ft
ρ_o	mass density of air at sea level, slugs/cu ft
Δn	normal-acceleration increment, g units
U_e	effective gust velocity defined in reference 1, $\frac{2\ \Delta n\ W}{1.47 m \rho_o S V_e K}$, ft/sec
K	gust-alleviation factor (function of wing loading) defined in reference 1
μ_g	airplane mass ratio, $\frac{2W}{\rho m g \bar{c} S}$
K_g	gust factor (function of μ_g) defined in reference 2

U_{de} derived gust velocity defined in reference 2, $\dfrac{2\ \Delta n\ W}{1.47m\rho_o S V_e K_g}$, ft/sec

V_e equivalent airspeed, mph

V_C design cruising speed, mph (ref. 8, p. 3)

l average flight miles required to equal or exceed a given value of gust velocity

N total number of observations in a sample of data

τ average flight time per V-G record, hr

P probability that maximum value on a V-G record will equal or exceed a given value

u location parameter of distribution of extreme values (ref. 9, p. 2)

α scale parameter of distribution of extreme values (ref. 9, p. 2)

A bar over a symbol denotes the mean value of the variable.

SCOPE OF DATA

Table I shows the scope of the V-G data collected from 1933 to 1950 as presented in references 3 to 7. In accordance with the procedures of these references, the data are grouped into three time intervals - 1933 to 1941, 1941 to 1945, and 1945 to 1950 - to denote the operations prior to, during, and after a wartime period. The type of airplane and the route are identified by combinations of a capital letter and a Roman numeral, such as A-I, B-II, and C-III. The airplanes and routes which correspond to those given in reference 3 are identified herein by the same combinations to facilitate comparisons of present and older results.

Table II gives the airplane characteristics used for evaluating the data. The values given were obtained either from the Civil Aeronautics Administration and the design manual of the airplane manufacturer, or were computed as indicated in the table.

METHOD OF CONVERSION AND RESULTS

The method of converting the measurements of U_e into terms of U_{de} follows directly from the definitions of these two quantities. The effective gust velocity U_e is defined by the relation

$$U_e = \frac{2 \Delta n W}{1.47 m \rho_o S V_e K} \tag{1}$$

where K is the gust-alleviation factor and is a function of wing loading (see ref. 1) and 1.47 is a factor for converting the airspeed from miles per hour to feet per second. The derived gust velocity of reference 2 is defined by the relation

$$U_{de} = \frac{2 \Delta n W}{1.47 m \rho_o S V_e K_g} \tag{2}$$

In this relation K_g is a function of the airplane mass ratio μ_g and is based on a one-minus-cosine gust profile in contrast with the linear-gradient gust profile assumed in equation (1). From equations (1) and (2),

$$U_{de} = U_e \frac{K}{K_g} \tag{3}$$

This relation permits simple conversion of the values of U_e obtained from measurements from a given airplane to values of U_{de}. It might be noted that in calculating U_{de} the effects of air density on the airplane response are included since the value of K_g depends upon the mass ratio, which in turn is a function of air density. For the present calculations (as was done in ref. 3 and refs. 5 to 7), an operating weight was assumed equal to 85 percent of the airplane weight and a lift-curve slope was computed by using the relation $m = \frac{6A}{A + 2}$ as indicated in table II. (Gust velocities are not given in reference 4 in terms of U_e; therefore, the normal-acceleration and airspeed data upon which that paper is based were reevaluated to obtain values of U_e and U_{de} for this report.) Inasmuch as V-G records do not indicate the altitudes flown, it was necessary to estimate average operating altitudes from information received from

the operator and from analysis of time-history data obtained on the airlines. The values of K/K_g obtained for the various airplanes range from about 1.6 to 2.0 and are given in table II.

The application of equation (3) to the individual values of U_e used to obtain the distributions of references 3 to 7 yielded values of U_{de} for each of the airplanes listed in table I. The results are summarized in table III as frequency distributions of U_{de}, along with the values of the statistical parameters $\overline{U}_{de}$, u, and α which are useful for fitting the distributions of extreme values (see ref. 9) to these observed frequency distributions.

The statistical parameters given in table III were used to fit distributions of extreme values to the observed distributions of the data by the method of moments described in reference 9, and the probabilities P of exceeding given values of U_{de} were determined. For convenience in comparing the various distributions, the probabilities were converted to flight distances by using the relation

$$l = \frac{0.8V_C\tau}{P} \qquad (4)$$

In this relation l is the average flight miles required to exceed given values of U_{de}, τ is the average flight time in hours per record for the respective data sample, and $0.8V_C$ is an assumed average operating airspeed. The results obtained by the application of equation (4) to the present data are shown in figure 1, which summarizes the gust velocities encountered in the various operations. The dashed portions of the curves indicate extrapolations beyond the limits of the data.

As a simple comparison of the levels of the gust velocities encountered in the various operations, the expected largest values of U_{de} at 10^7 flight miles were obtained from figure 1 and are listed in table IV. The corresponding values of U_e obtained from the data of references 3 to 7 for 10^7 flight miles are also given for comparison. (The values of U_{de} shown in table IV differ in some cases from those obtained by scaling the values of U_e by using equation (3). These differences are small and are mainly the result of minor differences in grouping and in curve-fitting methods used.)

In general, the relative levels of the turbulence encountered in the various operations are unchanged. The one exception to this trend appears in the D-IV operations (prewar and wartime), which now appear from the U_{de} values to have encountered turbulence of an average intensity, whereas on the basis of the U_e values these operations were previously shown as the smoothest.

SUMMARY OF RESULTS

The airspeed and normal-acceleration data obtained from V-G records during the period from 1933 to 1950 have been reevaluated in terms of the recently defined "derived" gust velocity U_{de}. The reevaluation was made on the basis of a "derived" gust velocity U_{de}, which is related to the "effective" gust velocity U_e by a conversion factor that is a function of the type of airplane and operating altitude. Although the value of the conversion factor varies from about 1.6 to 2.0 for the data presented, the conclusions drawn from the previously presented data based on U_e (in particular, the relative levels of turbulence indicated between different routes) remain essentially unchanged.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 8, 1953.

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TABLE I

SCOPE OF V-G DATA ANALYZED IN AIRLINE OPERATIONS FROM 1933 TO 1950

Airplane	Routes flown		Dates of operation	Number of records analyzed	Av. flight hours per record, τ	Total record hours
Period from 1933 to 1941						
A	I	Newark-Seattle-Oakland	July 1933 to Apr. 1937	30	305	9,168
B	II	Miami-Newark-Boston	June 1935 to Dec. 1940	18	367.5	6,615
C	III	Miami-Buenos Aires	Apr. 1936 to Dec. 1939	117	95.1	11,124
D	IV	San Francisco-Hawaii-Hong Kong	June 1936 to Dec. 1941	100	128.1	12,807
E	I	Newark-Seattle-Oakland	July 1937 to Dec. 1941	15	645	9,691
E	V	Boston-Newark-Los Angeles	Feb. 1937 to Oct. 1939	37	275	10,187
E	VI	Newark-Kansas City-Los Angeles	Sept. 1938 to Oct. 1940	11	295	3,232
F	III	Caribbean region and northern part of South America	Apr. 1940 to Dec. 1941	83	29	2,386
Period from 1941 to 1945						
D	IV	San Francisco-Hawaii	Dec. 1941 to Jan. 1945	30	36.1	1,084
E	I	Newark-Seattle-Oakland	Dec. 1941 to Dec. 1944	20	695	13,911
F	III	Caribbean region and northern part of South America	Dec. 1941 to Sept. 1944	193	53	10,261
Period from 1945 to 1950						
E	VII	New Orleans-Kansas City-Minot, N. D.	Oct. 1948 to Feb. 1950	79	303	23,940
G	II	New York-Miami	Nov. 1947 to Feb. 1950	194	248	48,187
H	III	Miami-Caribbean region-South America	Nov. 1947 to May 1949	27	247	6,677
H	IV	San Francisco-Australia-Orient	Aug. 1947 to Apr. 1949	69	231	15,951
J	VIII	New York-Seattle	Dec. 1948 to Apr. 1950	388	99.4	38,578

TABLE II

AIRPLANE CHARACTERISTICS

Airplane	Design gross wt., lb	Wing area, S, sq ft	Wing span, b, ft	Mean geometric chord, $\bar{c}$, ft	Aspect ratio, A	Design cruising speed, V_C, mph	Estimated operating altitude, ft	Mass ratio, μ_g (a)	Gust factor			Slope of lift curve, computed from $m = \frac{6A}{A + 2}$
									K_g	K (b)	$\frac{K}{K_g}$	
A	13,400	836	74	11.3	6.6	180	5,000	7.94	0.526	0.960	1.83	4.60
B	18,560	939	85	11.0	7.7	215	5,000	9.75	.570	1.008	1.77	4.76
C	41,000	1,340	118.2	11.3	10.4	181	5,000	13.85	.637	1.098	1.73	5.04
D	50,000	2,145	130	16.5	7.9	168	5,000	7.62	.518	1.045	2.02	4.78
E	25,200	987	95	10.4	9.1	211	5,000	12.85	.621	1.064	1.71	4.92
F	45,000	1,486	107.3	13.9	7.8	230	5,000	11.75	.610	1.097	1.80	4.78
G	94,000	1,650	123	14.7	9.2	271	10,000	23.60	.725	1.190	1.64	4.93
H	70,700	1,461	117.5	13.6	9.5	224	10,000	21.57	.711	1.166	1.64	4.96
J	39,900	864	93.3	10.1	10.1	256	5,000	23.58	.725	1.160	1.60	5.00

[a]For 0.85 gross weight at estimated operating altitude.

[b]For 0.85 gross weight.

TABLE III

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS OF U_{de}

(a) Period 1933 to 1941

U_{de}, ft/sec	Number of observations for airplane and route -							
	A-I	B-II	C-III	D-IV	E-I	E-V	E-VI	F-III
4 to 8	-----	-----	-----	2	-----	-----	-----	-----
8 to 12	-----	-----	7	9	-----	-----	-----	3
12 to 16	1	2	20	32	-----	2	5	33
16 to 20	1	7	28	40	2	1	0	46
20 to 24	5	7	65	35	3	9	6	30
24 to 28	3	5	57	34	7	14	4	29
28 to 32	8	7	27	21	3	16	4	13
32 to 36	12	3	19	16	8	9	2	7
36 to 40	11	3	5	2	4	10	0	1
40 to 44	7	0	2	4	1	5	1	3
44 to 48	6	1	2	0	2	5	-----	1
48 to 52	2	1	2	3	-----	0	-----	-----
52 to 56	1	-----	-----	1	-----	1	-----	-----
56 to 60	2	-----	-----	0	-----	2	-----	-----
60 to 64	1	-----	-----	0	-----	-----	-----	-----
64 to 68	-----	-----	-----	0	-----	-----	-----	-----
68 to 72	-----	-----	-----	1	-----	-----	-----	-----
Total, N	60	36	234	200	30	74	22	166
$\overline{U}_{de}$, ft/sec	36.46	26.66	24.30	23.08	31.06	32.27	24.36	21.51
u	32.10	22.81	21.11	19.02	27.72	28.18	20.95	18.46
α	0.13	0.15	0.18	0.14	0.17	0.14	0.17	0.19

TABLE III - Continued

FREQUENCY DISTRIBUTIONS AND STATISTICAL

PARAMETERS OF U_{de}

(b) Period 1941 to 1945

U_{de}, ft/sec	Number of observations for airplane and route -		
	D-IV	E-I	F-III
4 to 8	-----	-----	1
8 to 12	3	-----	1
12 to 16	2	-----	12
16 to 20	8	-----	27
20 to 24	11	2	61
24 to 28	19	10	72
28 to 32	10	4	81
32 to 36	4	10	57
36 to 40	1	6	38
40 to 44	0	2	14
44 to 48	1	0	9
48 to 52	0	0	5
52 to 56	0	4	3
56 to 60	1	0	1
60 to 64	-----	0	0
64 to 68	-----	0	1
68 to 72	-----	0	1
72 to 76	-----	1	2
76 to 80	-----	0	-----
80 to 84	-----	0	-----
84 to 88	-----	1	-----
Total, N	60	40	386
$\overline{U}_{de}$, ft/sec	25.26	36.30	29.67
u	21.70	30.30	25.58
α	0.16	0.10	0.14

TABLE III - Concluded

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS OF U_{de}

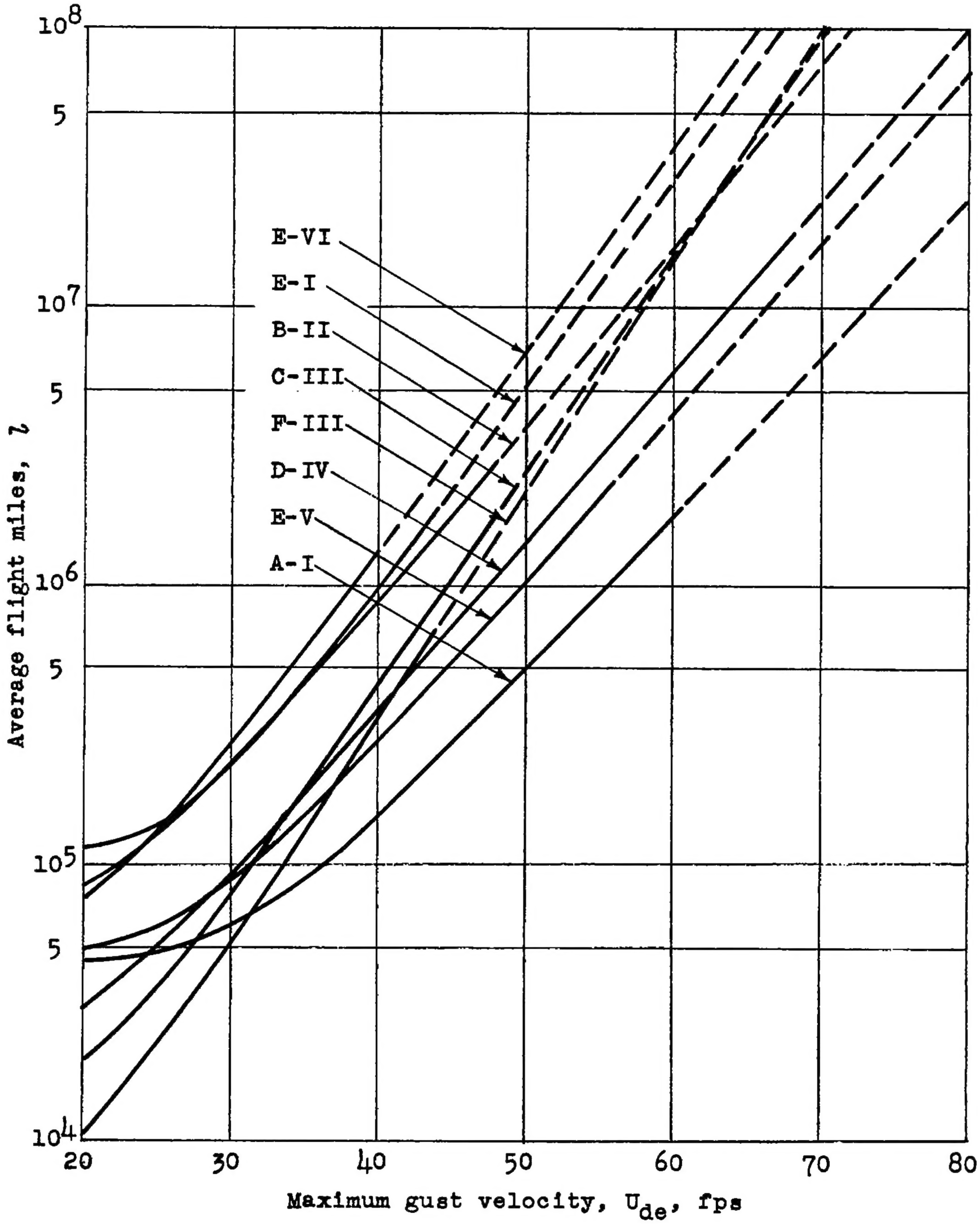
(c) Period 1945 to 1950

U_{de}, ft/sec	Number of observations for airplane and route -				
	E-VII	G-II	H-III	H-IV	J-VIII
12 to 16	-----	3	-----	2	-----
16 to 20	5	12	3	20	1
20 to 24	8	30	5	17	18
24 to 28	24	74	15	50	82
28 to 32	24	53	7	18	133
32 to 36	33	62	4	15	203
36 to 40	24	67	7	10	140
40 to 44	12	26	6	5	86
44 to 48	9	22	4	1	49
48 to 52	10	9	2	-----	26
52 to 56	3	18	1	-----	16
56 to 60	2	6	-----	-----	11
60 to 64	1	2	-----	-----	4
64 to 68	1	0	-----	-----	3
68 to 72	2	1	-----	-----	2
72 to 76	-----	1	-----	-----	0
76 to 80	-----	1	-----	-----	1
80 to 84	-----	0	-----	-----	1
84 to 88	-----	0	-----	-----	-----
88 to 92	-----	1	-----	-----	-----
Total, N	158	388	54	138	776
$\overline{U}_{de}$, ft/sec	35.49	34.52	32.52	27.74	36.31
u	30.98	29.80	28.40	24.97	32.58
α	0.13	0.12	0.14	0.21	0.16

TABLE IV

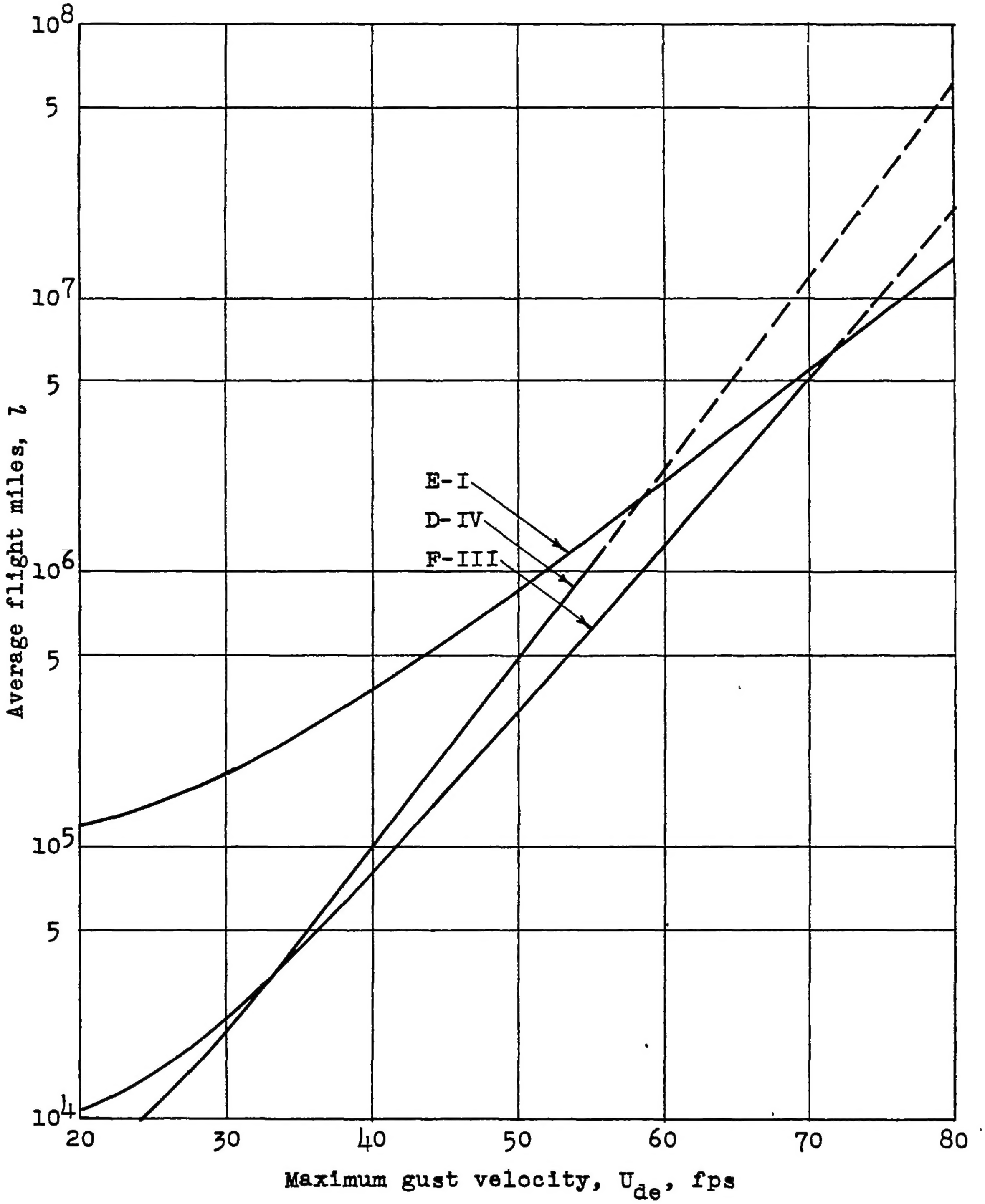
VALUES OF U_{de} AND U_e AT 10^7 FLIGHT MILES

Airplane and route	U_{de}	U_e
Period 1933 to 1941		
A-I	73.3	42.1
B-II	56.5	33.4
C-III	57.5	33.7
D-IV	63.8	31.1
E-I	53.8	31.4
E-V	66.3	37.9
E-VI	52.2	33.8
F-III	58.1	32.6
Period 1941 to 1945		
D-IV	68.8	35.2
E-I	76.5	47.3
F-III	74.7	42.8
Period 1945 to 1950		
E-VII	72.2	42.2
G-II	72.4	43.4
H-III	67.1	39.9
H-IV	51.2	32.0
J-VIII	72.6	45.5



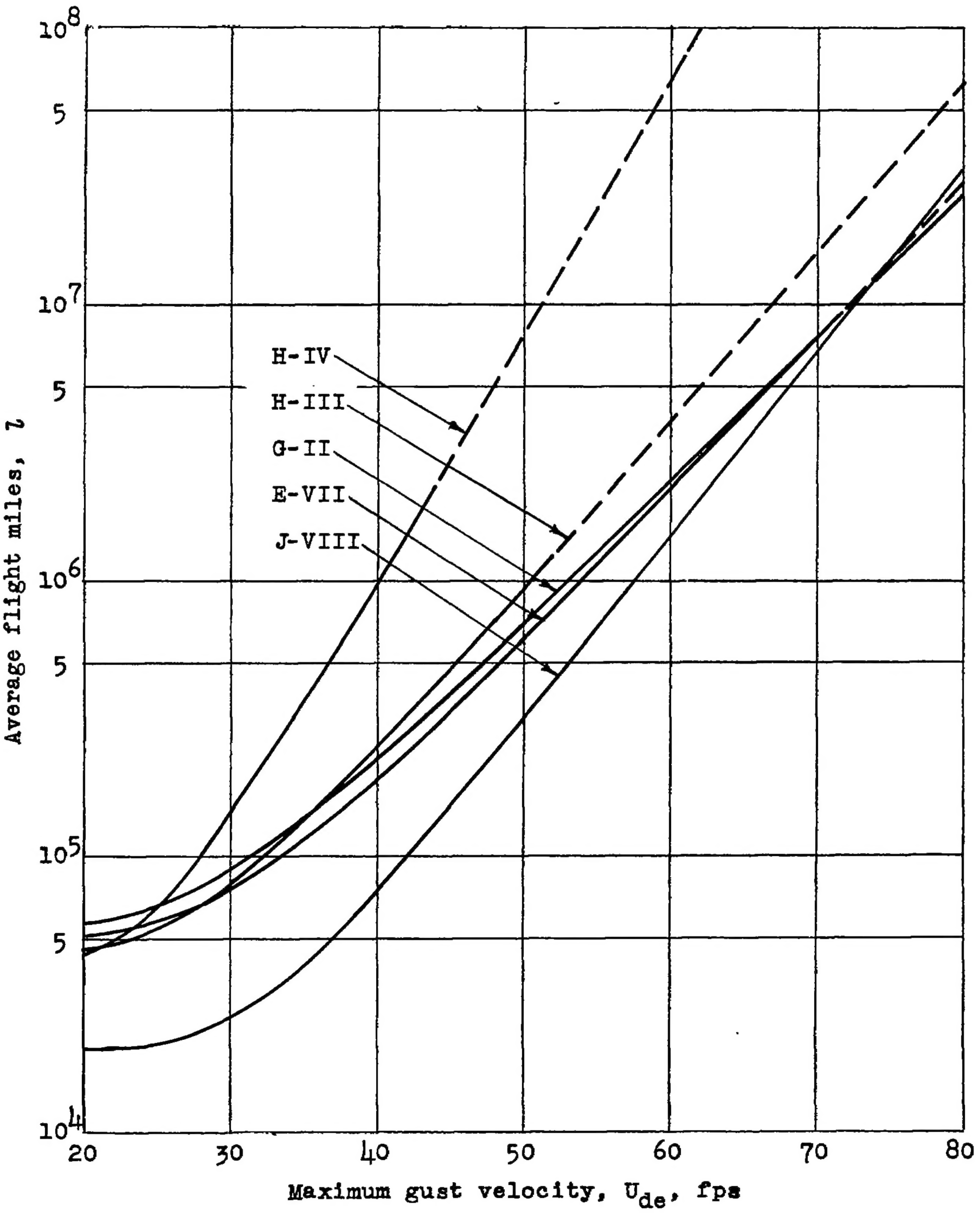
(a) Period 1933 to 1941.

Figure 1.- Average flight miles l for a maximum positive and negative gust velocity to equal or exceed a given value.



(b) Period 1941 to 1945.

Figure 1.- Continued.



(c) Period 1945 to 1950.

Figure 1.- Concluded.

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